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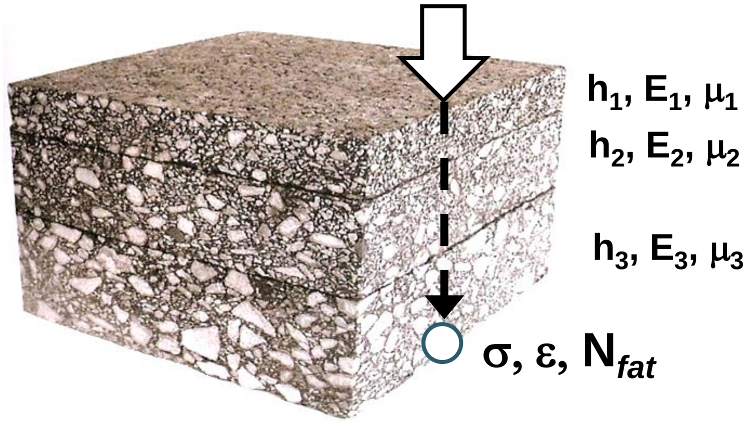
# Pavement Design considering Reclaimed Asphalt

**Michael P. Wistuba & Ivan Isailović**
ISBS, Technische Universität Braunschweig

**Int. Seminar on Asphalt Pavements, 12 April 2018, Opatija, Croatia**

# Contents

- Mechanistic Pavement Design in Germany and in Austria
- Fatigue evaluation when using Reclaimed Asphalt
- New approach based on sweep tests



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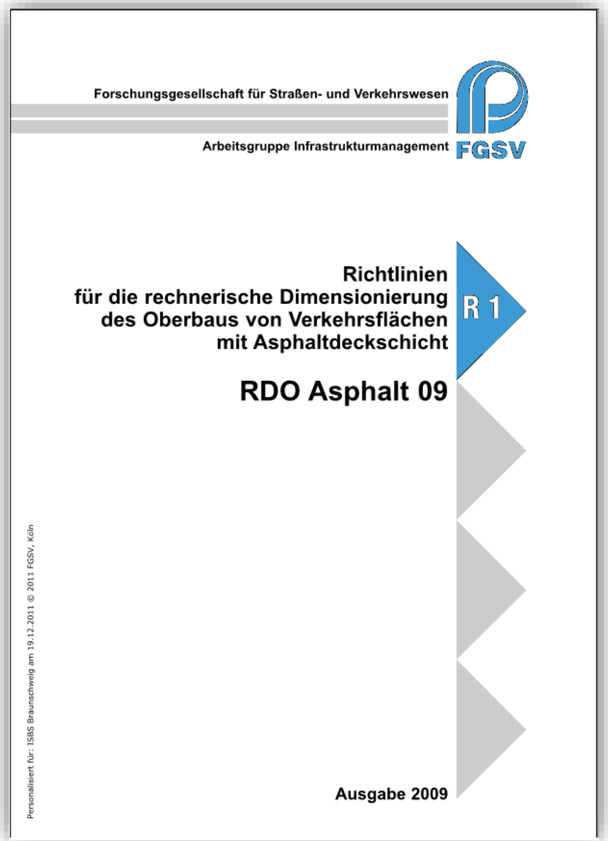
# The German and Austrian Pavement Design Guidelines

**Road and Transportation Research Association (FGSV)**

**Österreichische Forschungsgesellschaft Straße - Schiene – Verkehr (FSV)**


Forschungsgesellschaft für Straßen- und Verkehrswesen

Arbeitsgruppe Infrastrukturmanagement

FGSV

Richtlinien
für die rechnerische Dimensionierung
des Oberbaus von Verkehrsflächen
mit Asphaltdeckschicht

R 1

RDO Asphalt 09

Ausgabe 2009



## The Austrian Pavement Design Guide (RVS 03.08.68)

**Straßenplanung**
**Bautechnisches**
**Bautechnische Details**

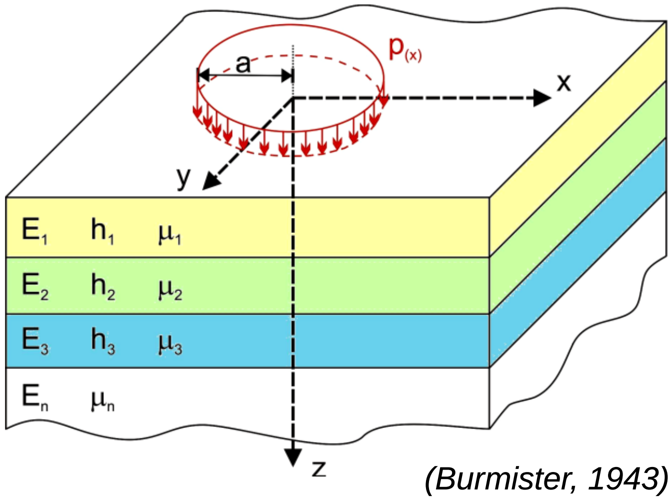
Blatt 0.0

**RECHNERISCHE DIMENSIONIERUNG VON ASPHALTSTRASSEN** — **RVS 03.08.68**

*Road Planning*
*Constructive*
*Constructive Details*
*Mechanistic Asphalt Pavement Design*

## Both design procedures are based on multilayer linear elastic theory

- layered elastic model
  - homogeneous, isotropic, and linear elastic materials
  - infinite horizontal layer extension; infinite vertical subgrade extension
  - stick or slip layer interfaces

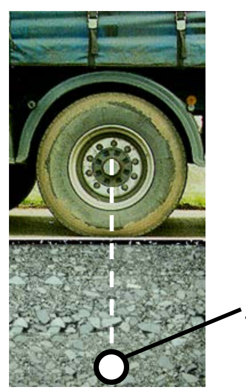



*(Burmister, 1943)*

- limited number of input data
  - layer thicknesses
  - material properties (E-Modulus, Poisson ratio, layer friction)
  - force (magnitude of wheel load) and load geometry (tire patch load)
- materials are not stressed beyond their elastic ranges
  - suitable for short-term loading at moderate temperatures
  - linear summation of the damaging effects of individual loads (Miner summation)

## Both design procedures are based on multilayer linear elastic theory

- relatively simple mathematical models applicable for high numbers of load repetitions
- crucial design criterion to avoid structural failure: material fatigue at the bottom of asphalt layers



$$\sigma_r = \frac{E}{(1+\nu)\cdot(1-2\cdot\nu)}\cdot\left\{(1-\nu)\cdot\frac{\delta u}{\delta r}+\nu\cdot\left(\frac{u}{r}+\frac{\delta w}{\delta z}\right)\right\}$$

$$\sigma_t = \frac{E}{(1+\nu)\cdot(1-2\cdot\nu)}\cdot\left\{(1-\nu)\cdot\frac{u}{r}+\nu\cdot\left(\frac{u}{r}+\frac{\delta w}{\delta z}\right)\right\}$$

$$\sigma_z = \frac{E}{(1+\nu)\cdot(1-2\cdot\nu)}\cdot\left\{(1-\nu)\cdot\frac{\delta w}{\delta z}+\nu\cdot\left(\frac{u}{r}+\frac{\delta u}{\delta r}\right)\right\}$$

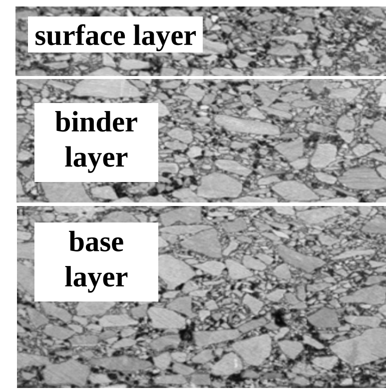
$$\tau_{rz} = \frac{E}{2\cdot(1+\nu)}\cdot\left\{\frac{\delta u}{\delta z}+\frac{\delta w}{\delta r}\right\}$$

# Input parameters are related to local conditions

**Traffic data**

**Climate data**


**Pavement data**




- **layer thicknesses**
- **material parameters (Poisson's ratio, performance properties)**

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## Input parameters are related to local conditions

**Traffic data**


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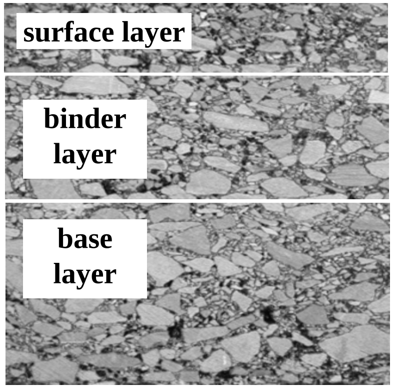
**Pavement data**




- **layer thicknesses**
- **material parameters (Poisson's ratio, performance properties)**

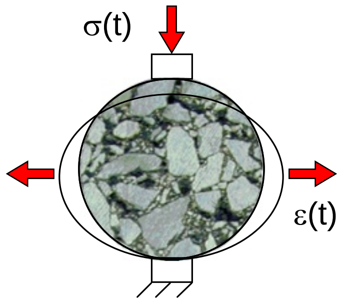
# Mechanistic Pavement Design in Germany / Austria

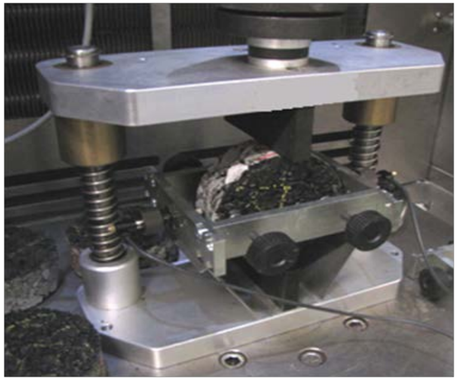


## Material parameters obtained from laboratory testing

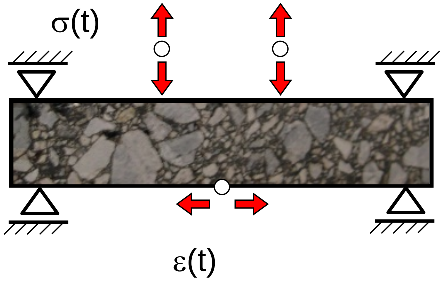
- **Stiffness** of all asphalt layers
- **Fatigue resistance** of base layer(s)

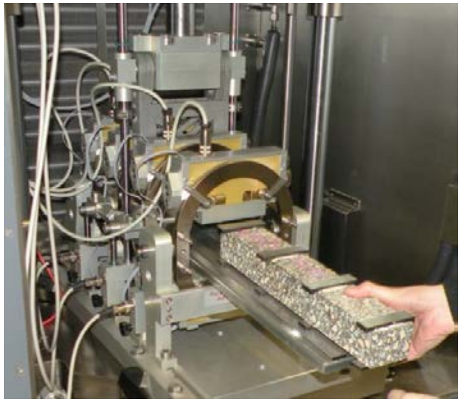
### Indirect Tensile Test



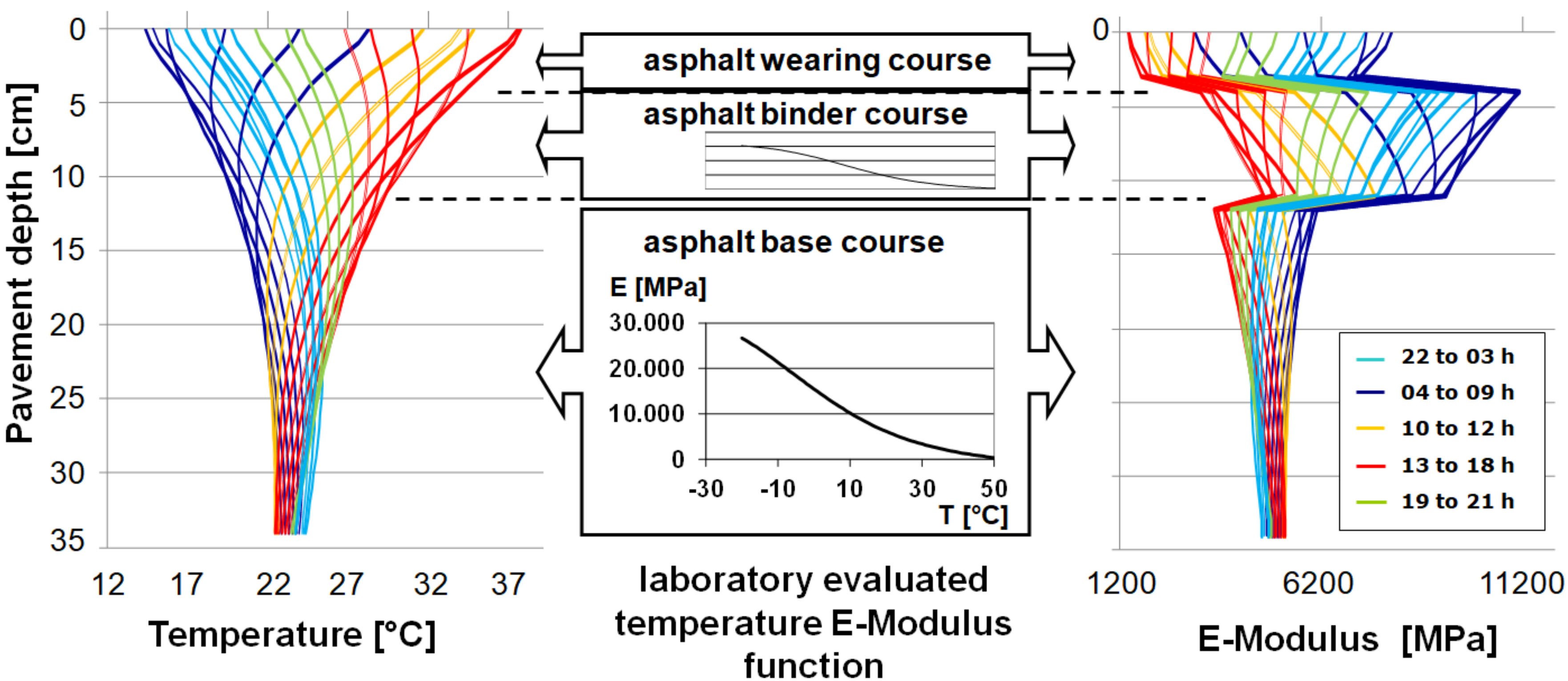



### 4 Point Bending Beam Test

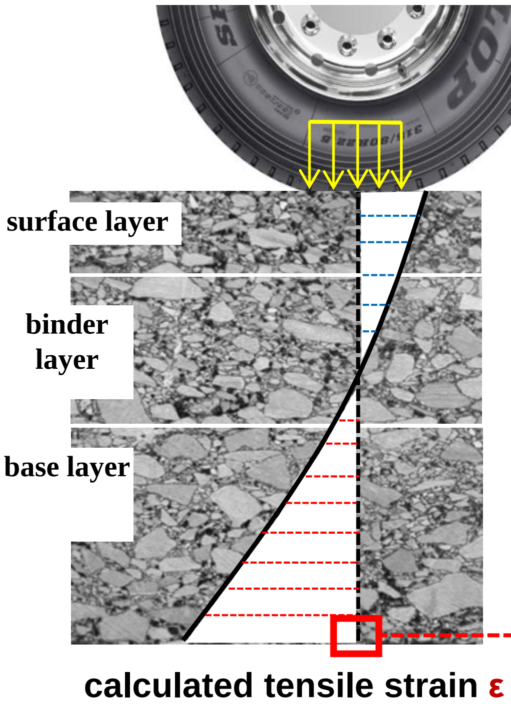


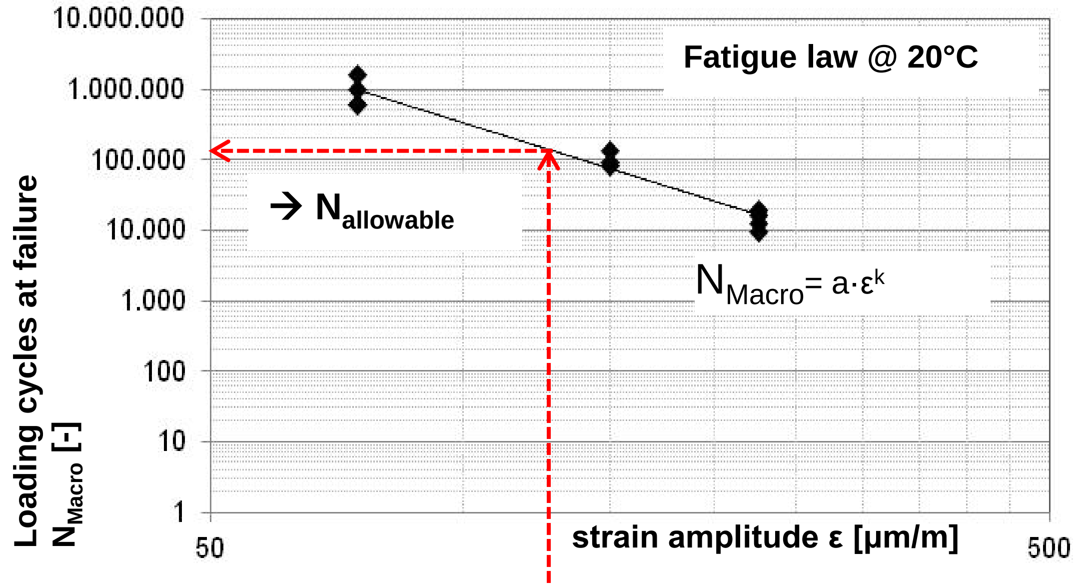



**Stiffness tests of all asphalt materials at several temperatures and frequencies for consideration of pavement stiffness due to temperature variations**



# **Fatigue tests** of base layers **at a test temperature of 20°C** for estimation of pavement durability based on calculated stress/strain



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# Fatigue tests of base layers at a test temperature of 20°C

## 4 Point Bending Beam Test

$$N_{allowable} = \frac{k_1(T)}{F} \cdot \left( \frac{E^*}{\sigma_V} \right)^{k_2(T)}$$

$$k_1(T) = 10^{-\left(0{,}0077 \cdot T^2 - 0{,}4859 \cdot T + 17{,}602\right)}$$

$$k_2(T) = 0{,}0015 \cdot T^2 - 0{,}0875 \cdot T + 6{,}1803$$

**temperature correction through factors $k_1$ and $k_2$**

## Indirect Tensile Test

$$N_{allowable} = \frac{SF}{F} \cdot a \cdot \varepsilon^k$$

**unique fatigue law, no temperature correction**

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# Fatigue tests of base layers at a test temperature of 20°C

## 4 Point Bending Beam Test

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$$k_2(T) = 0,0015 \cdot T^2 - 0,0875 \cdot T + 6,1803$$

**temperature correction through factors $k_1$ and $k_2$**

**→ need to be adjusted**

## Indirect Tensile Test

$$N_{allowable} = \frac{SF}{F} \cdot a \cdot \varepsilon^k$$

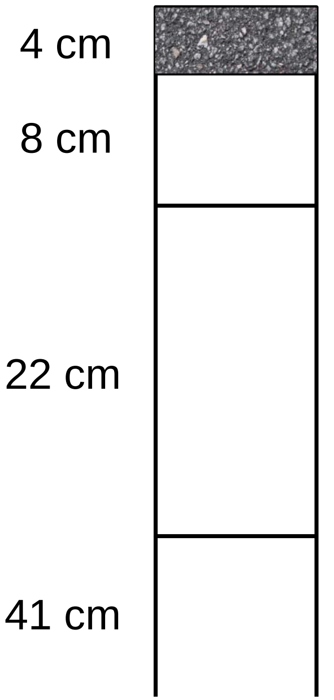
**unique fatigue law, no temperature correction**

**→ simple, but problematic**

## Pavement Design - Example

- Traffic load = 100 Mio. equivalent 10 t axes
- Stiffness tests at +20, +10, +0 and -10°C

Indirect Tensile Test



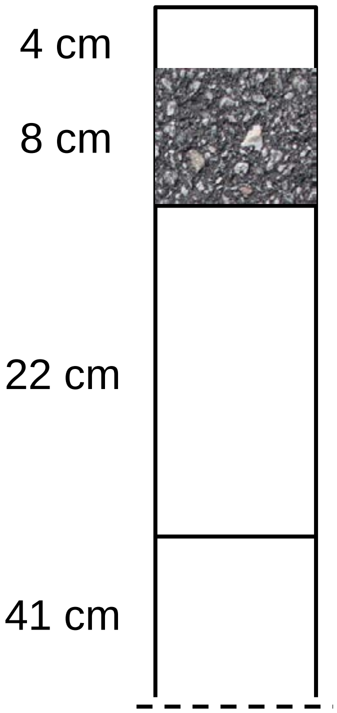

### Stiffness: surface course

| Temperatur [°C] | –20 | –15 | –10 | –5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steifigkeits-modul [MPa] | 26.319 | 24.664 | 22.196 | 19.172 | 16.255 | 13.443 | 10.729 | 8.111 | 5.581 | 3.425 | 2.119 | 1.332 | 850 | 550 | 360 |

# Pavement Design - Example

- Traffic load = 100 Mio. equivalent 10 t axes
- Stiffness tests at +20, +10, +0 and -10°C

**Indirect Tensile Test**




**Stiffness : binder course**

| Temperatur [°C] | –20 | –15 | –10 | –5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steifigkeits-modul [MPa] | 30.473 | 29.449 | 27.876 | 25.502 | 22.214 | 18.913 | 15.729 | 12.655 | 9.686 | 6.817 | 4.124 | 2.402 | 1.424 | 858 | 525 |

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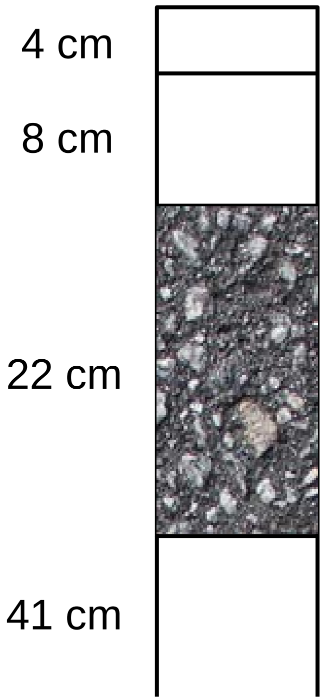
# Pavement Design - Example

- Traffic load = 100 Mio. equivalent 10 t axes
- Stiffness tests at +20, +10, +0 and -10°C

**Indirect Tensile Test**




**Base course in three different ageing conditions:**
- **fresh**
- **1 x aged (4 days in oven at 80 °C)**
- **2 x aged (8 days in oven at 80 °C)**

**Determination of fatigue properties using Indirect Tensile Test at 20°C**

unbound base layer

# Pavement Design - Example

- **Material parameters of asphalt base course (AC 22 TS)**

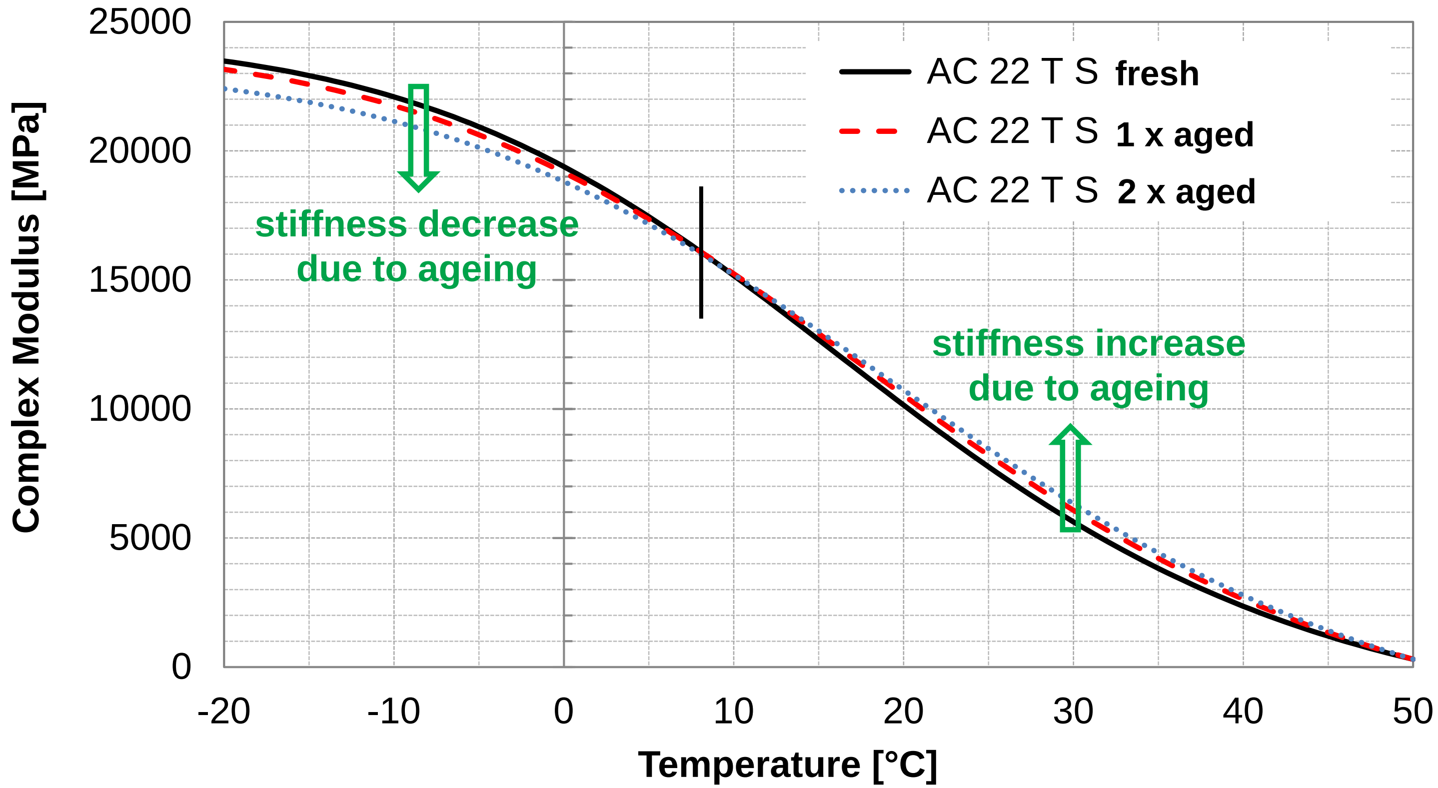
| | | |
|---|---|---|
| ≤ 0.063 mm | M.-% | 5 |
| 0.063 – 0.125 mm | M.-% | 1.2 |
| 0.125 – 0.25 mm | M.-% | 2.7 |
| 0.25 - 1 mm | M.-% | 11.4 |
| 1 - 2 mm | M.-% | 8.2 |
| 2 – 5.6 mm | M.-% | 12.2 |
| 5.6 - 8 mm | M.-% | 15.2 |
| 8 – 11.2 mm | M.-% | 14.3 |
| 11.2 - 16 mm | M.-% | 18.8 |
| 16 – 22.4 mm | M.-% | 9.9 |
| 22.4 – 31.5 mm | M.-% | 1.1 |
| Summe | M.-% | 100 |
| **Aggregate** | - | Limestone |
| **RAP** | M.-% | 30 |
| **Binder** | - | 50/70 |
| **Binder content** | M.-% | 4.1 |
| **Bulk density** | g/cm³ | 2.564 |
| **Density** | g/cm³ | 2.374 |
| **Air void** | V.-% | 7.4 |

| - | AC 22 T S fresh | AC 22 T S 1 x aged | AC 22 T S 2 x aged |
|---|---|---|---|
| **Ring and Ball [°C]** | 52.2 | 60.4 | 61.4 |
| **Average density of ϕ 150 mm samples [g/cm³]** | **2.364** | **2.356** | **2.358** |
| **Standard deviation [g/cm³]** | 0.0062 | 0.0087 | 0.0175 |

# Pavement Design – Example

- **Stiffness tests at +20, +10, +0 and -10°C**

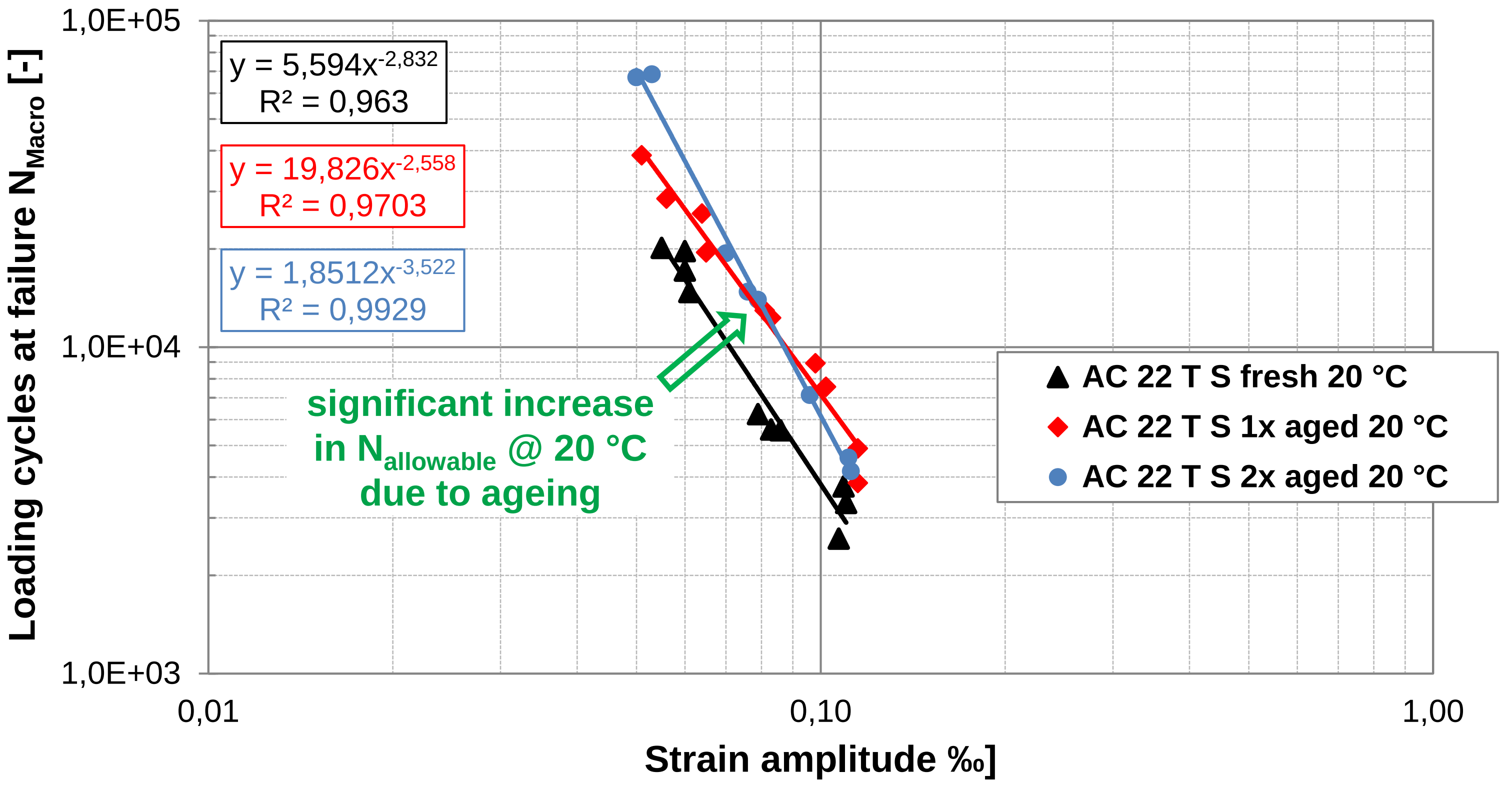
**Indirect Tensile Test**



# Pavement Design – Example

- **Fatigue tests at 20 °C and 3 stress amplitudes (0.35; 0.475; 0.60 MPa; 3 test repl.)**

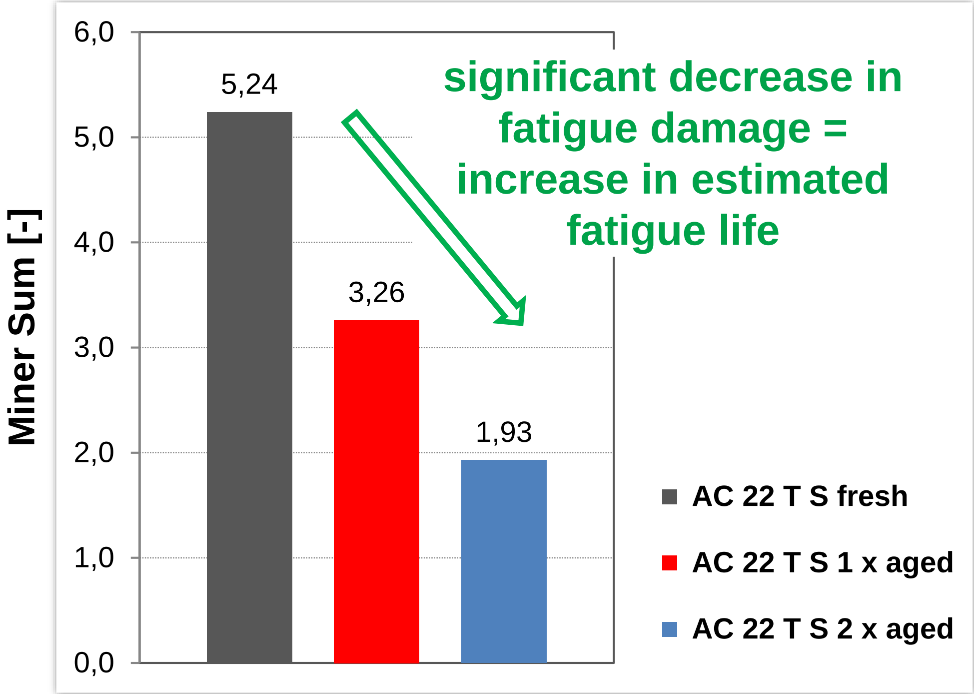
**Indirect Tensile Test**



# Pavement Design – Example

Indirect Tensile Test

- **Fatigue tests at 20 °C and 3 stress amplitudes (0.35; 0.475; 0.60 MPa; 3 test repl.)**
- **Fatigue life estimation:**




**Surprise!**

→ **aged material more durable??**

→ **more durable pavement when more Reclaimed Asphalt is used??**

**Explanation:**

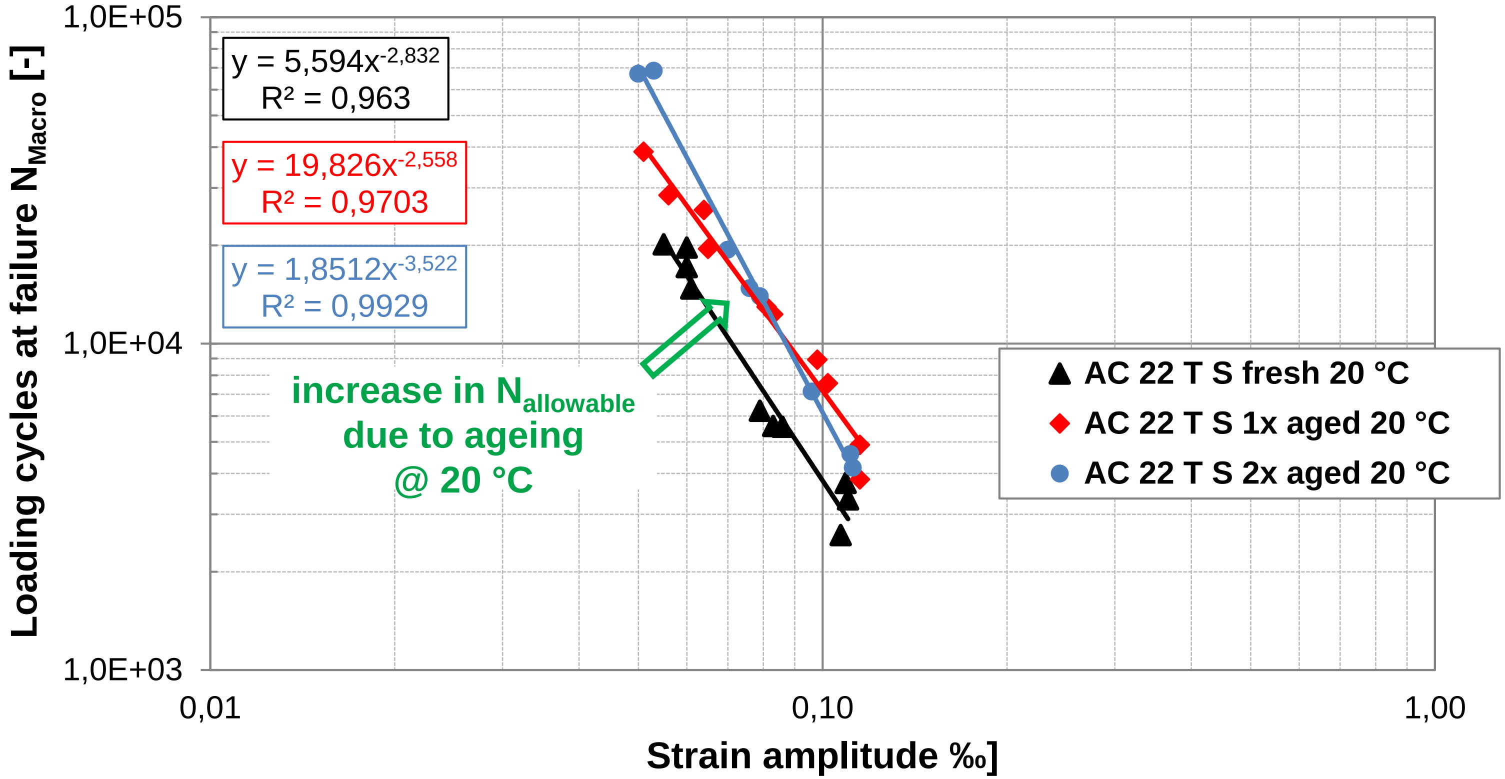
→ **Fatigue law derived at 20°C does not tell the full story, at lower temperatures this may change significantly!**

→ **Be careful when designing pavements with Reclaimed Asphalt!**

# Pavement Design – Example

- Fatigue tests at 20 °C and at 0°C

Indirect Tensile Test



# Fatigue evaluation when using Reclaimed Asphalt

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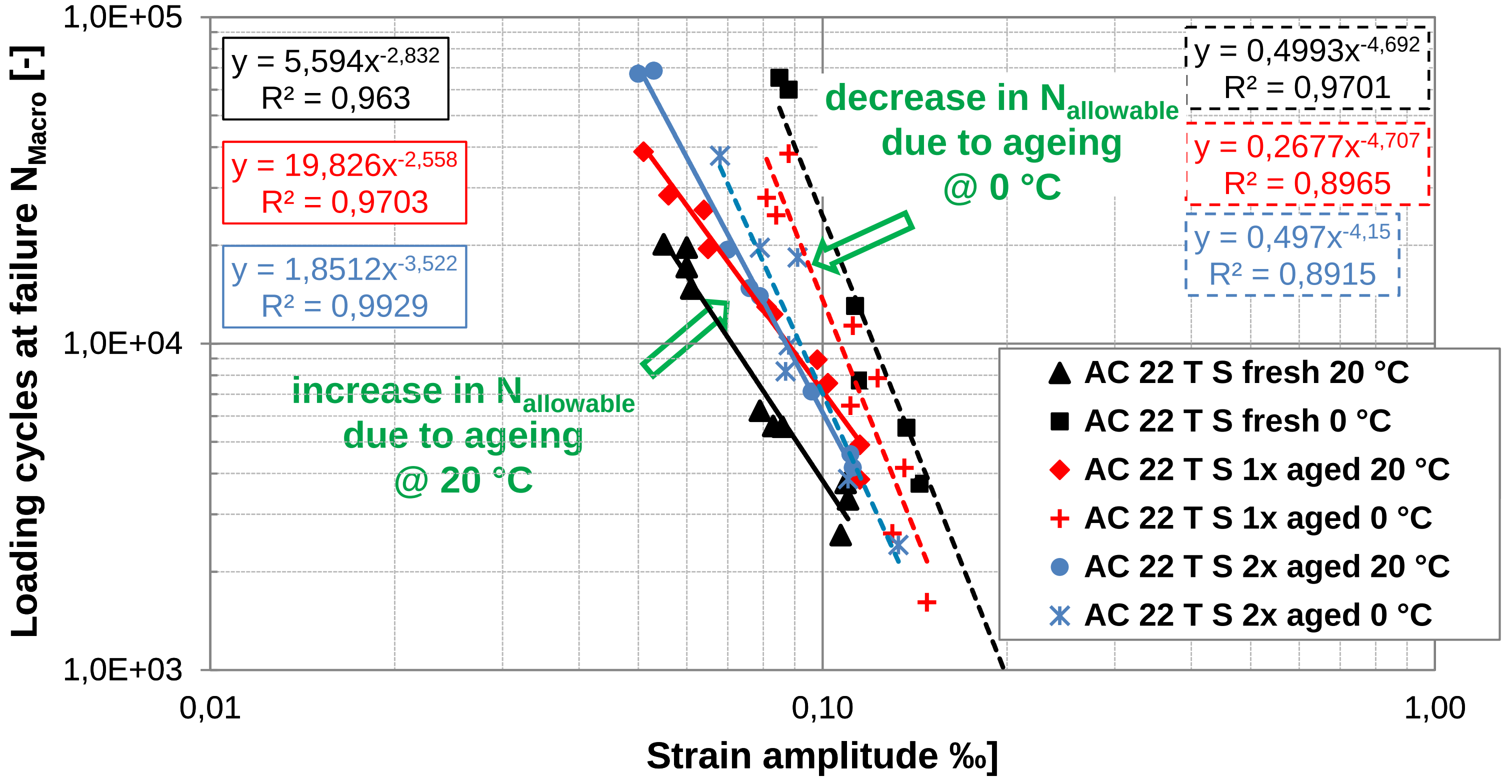
## Pavement Design – Example

- Fatigue tests at 20 °C and at 0°C

Indirect Tensile Test



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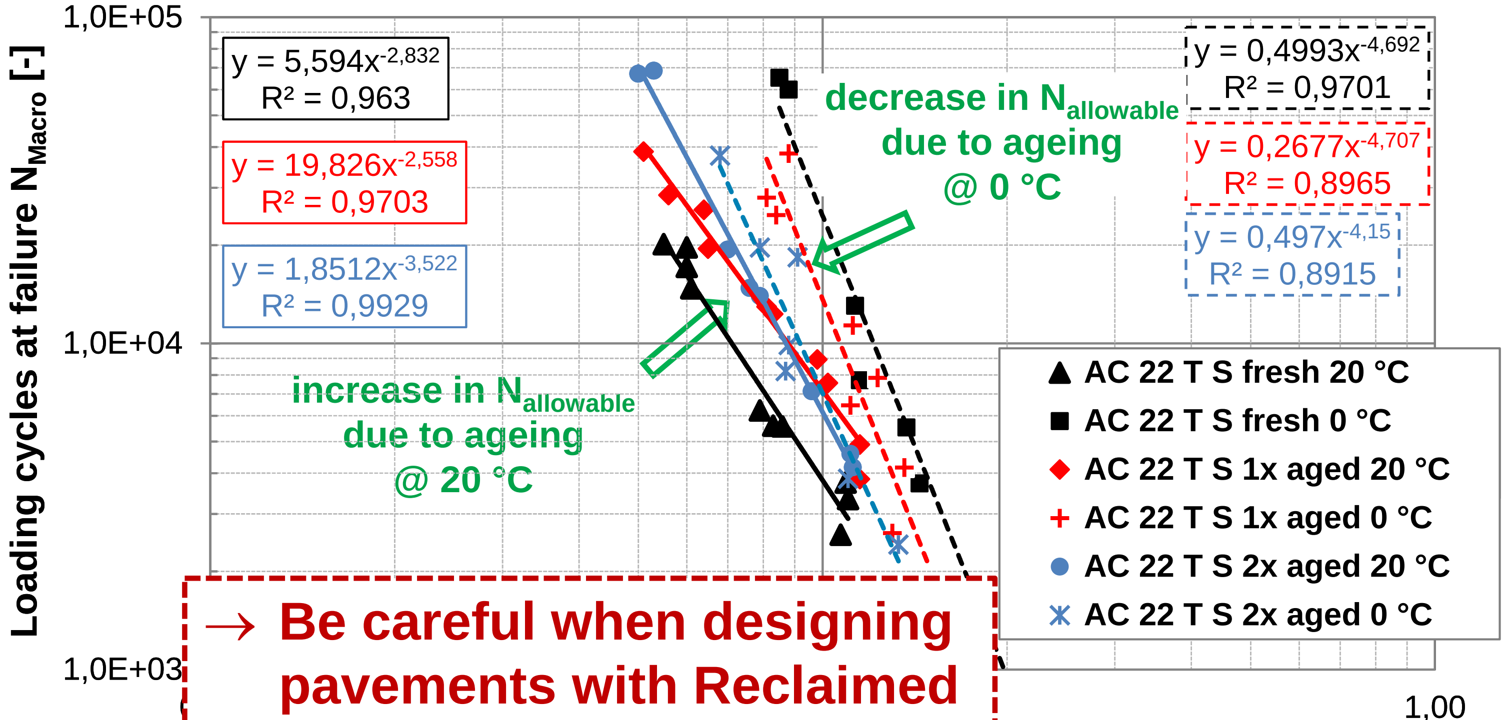
# Pavement Design – Example

- Fatigue tests at 20 °C and at 0°C

Indirect Tensile Test




→ **Be careful when designing pavements with Reclaimed Asphalt!**

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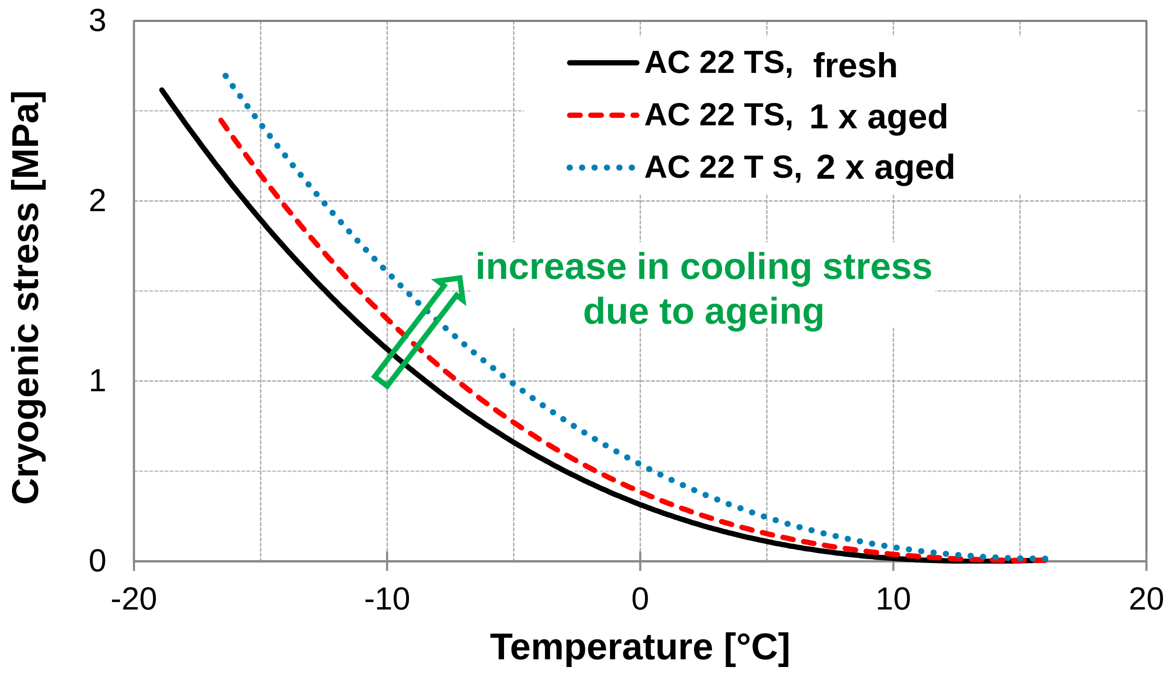
## Pavement Design – Example

- **Tensile Stress Restrained Specimen Test (TSRST): cooling rate 10 °C/h with restrained deformation until failure**

TSRST




→ **in addition material may be more brittle at lower temperatures and therefore more susceptible to cracking!**

# Pavement Design – Example

## Conclusions from this example

- Investigation of Fatigue Performance and Pavement Design require consideration of full temperature range.
- Be careful especially when using asphalt mixtures containing high amount of Reclaimed Asphalt, as existing Pavement Design Methods may lead to wrong results, if temperature dependency of fatigue law is ignored.


- **Problem:** significant increase in laboratory effort when performing conventional fatigue tests, as testing at more than one temperature is time-consuming and costly
  → for 1 temperature: 18 samples for 4PBB (A); 9 samples for ITT (D)

- Is there any possibility to consider fatigue temperature dependency with limited laboratory effort?

→ **Solution:** New fatigue test protocol based on sweep tests

# New fatigue test protocol

## Fatigue tests based on amplitude/frequency sweep

**During an *amplitude sweep* the amplitude of the deformation / shear stress is varied while the frequency is kept constant.**

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Johnson, C. M. 2010. Estimating asphalt binder fatigue resistance using an accelerated test method. PhD Thesis, University of Wisconsin, Civil & Environmental Engineering, Madison, United States.

Hintz, C., and Bahia, H. 2013. Simplification of linear amplitude sweep test and specification parameter. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2370, pp. 10-16.

Pérez Jiménez, F.E., Botella Nieto, R., Martínez Reguero, A.H., and Miró Recasens, J.R. 2013. Estimating the fatigue law of asphalt mixtures using a strain sweep test (EBADE test). Proc., 5th Int. EATA Conf., June 3-5, 2013, Braunschweig, Germany.

Isailović, I. & Wistuba, M. P. 2017. Sweep test protocol for fatigue evaluation of asphalt mixtures. Road Materials and Pavement Design, pp. 1-14, http://www.tandfonline.com/doi/full/10.1080/14680629.2018.1438305.

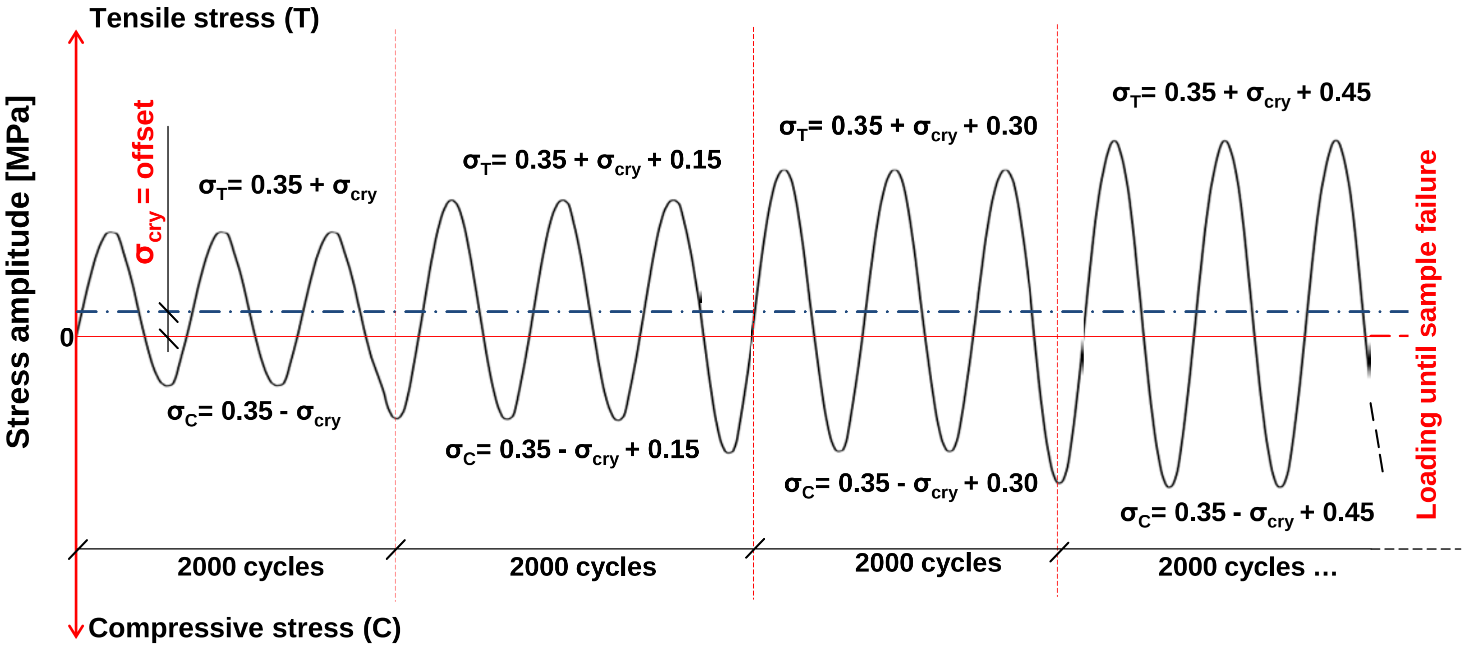
Isailović, I. 2018. Fatigue and recovery of road asphalt mixtures. PhD Thesis submitted to the Faculty of Architecture, Civil Engineering and Environmental Sciences, Technische Universität Braunschweig.

# New approach based on sweep tests

## Amplitude sweep tests for a range of temperatures

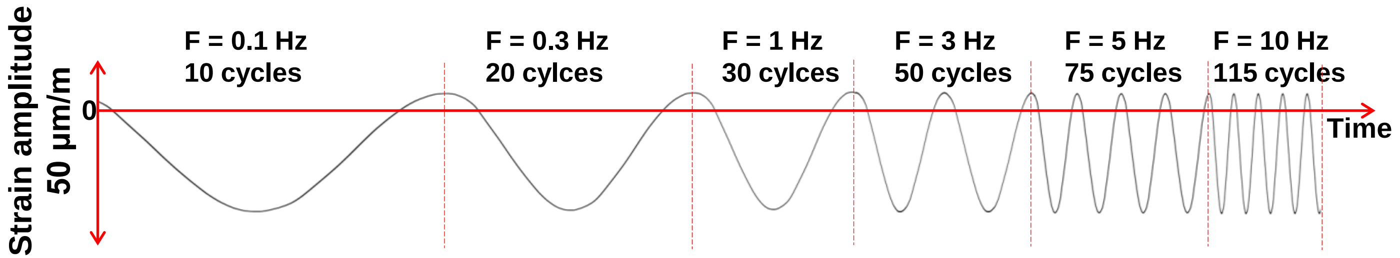
- **Uniaxial Tension-Compression Test in controlled stress mode**
- **Stepwise increase of stress amplitude until specimen failure**
- **2000 loading cycles per step**
- **Consideration of the following test temperatures: +20, +10, 0, -10 °C**
- **Consideration of cryogenic stress from TSRST for temperatures below 20 °C**

**UTCT**



# Frequency sweep tests for a range of temperatures

- in analogy to amplitude sweep tests: Uniaxial Tension-Compression Test in controlled strain mode

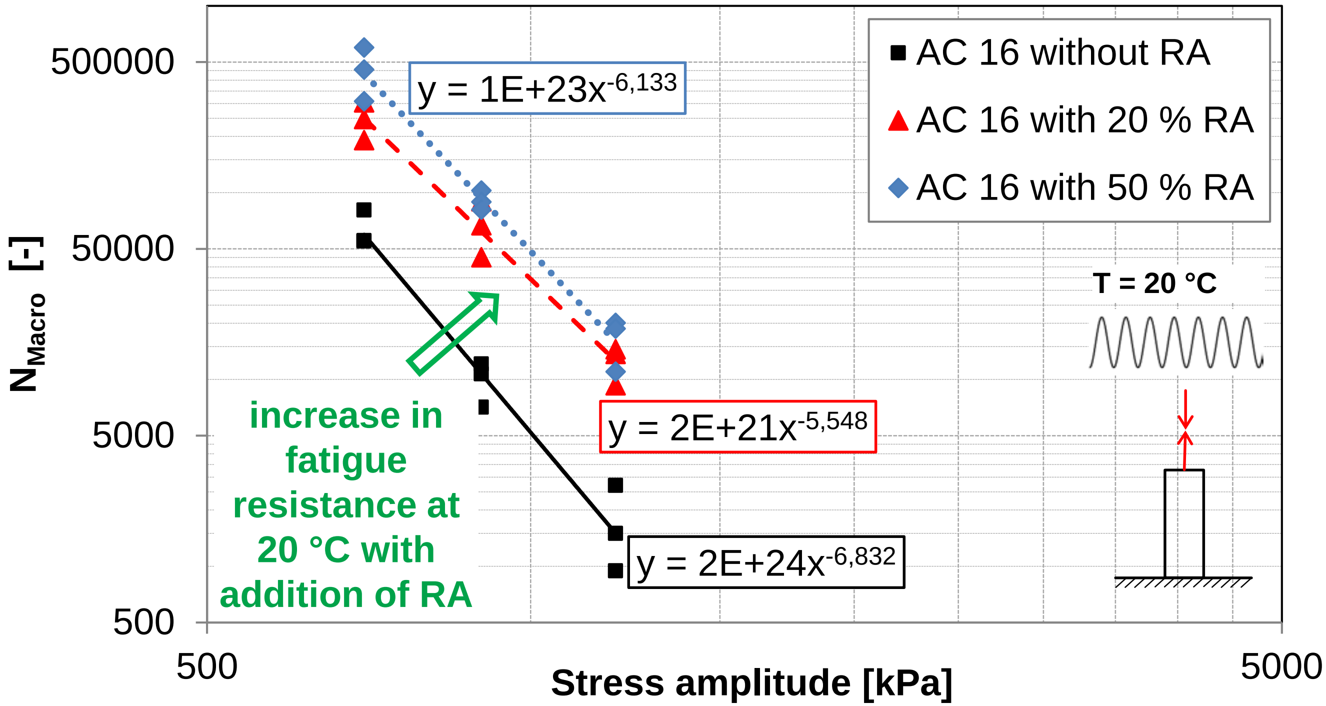



UTCT

- **stiffness evaluation** at different amplitudes, frequencies and temperatures
- **fatigue evaluation** at different amplitudes, frequencies and temperatures

# Exemplary results from comparative fatigue tests

- **AC 16 with 0, 20, and 50 % of Reclaimed Asphalt (RA)**
- **Conventional fatigue test results:**
  - test temperature 20 °C
  - 3 stress amplitudes: 0.7; 0.9; 1,2 MPa; 3 test replicates




UTCT @ 20 °C

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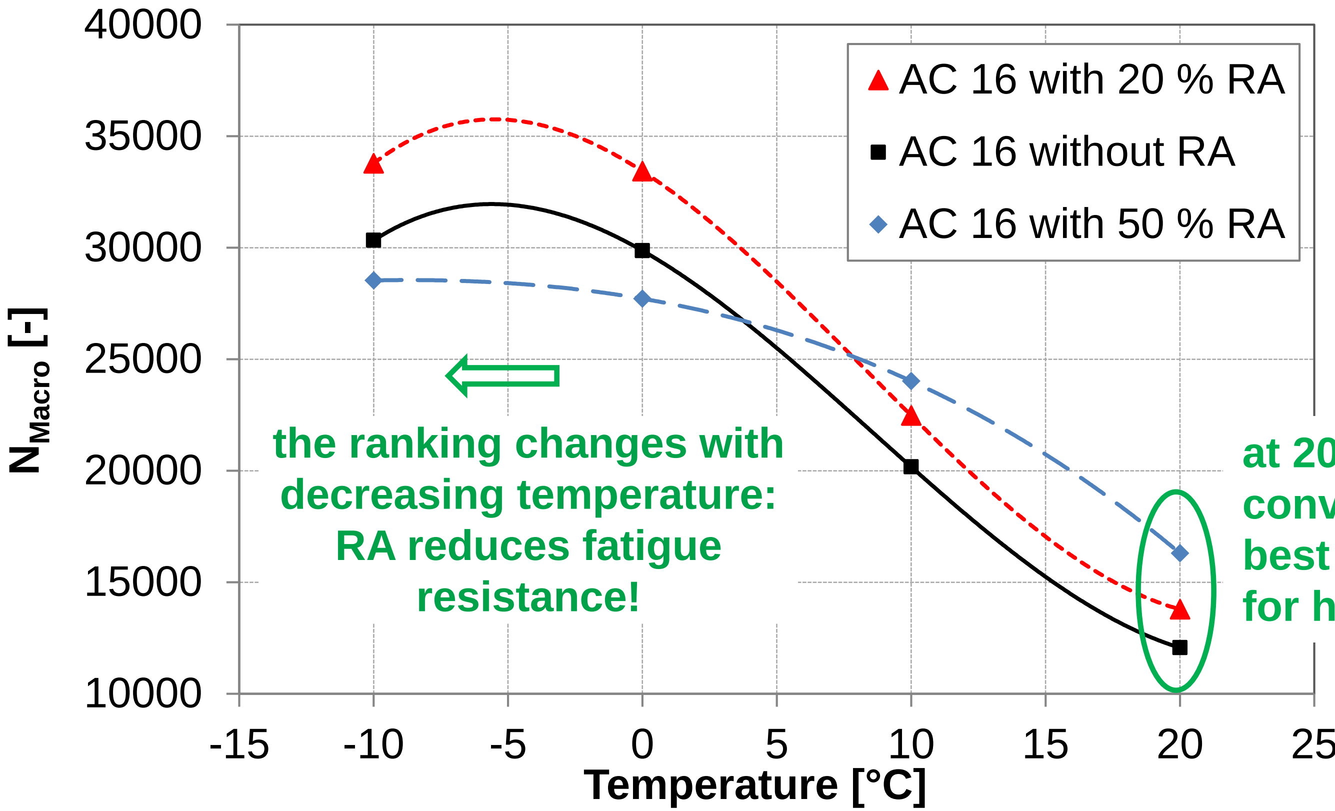
## Exemplary results from comparative fatigue tests

- **AC 16 with 0, 20, and 50 % of Reclaimed Asphalt (RA)**
- **Amplitude/frequency sweep fatigue test results:**
  - test temperatures: +20, +10, 0, -10 °C




at 20°C same results to conventional tests → best fatigue resistance for high amount of RA

UTCT @ 20, 10, 0, -10 °C

# Conclusions

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- **The dependency of fatigue performance on temperature needs to be considered in Pavement Design; if neglected, pavement life estimation may lead to wrong conclusions.**
  - **According to Austrian guidelines, the fatigue law is derived through 4PBB test at 20°C; its temperature dependency is considered through parameters $k_1$ and $k_2$. These parameters are not generally valid for any asphalt mixture in any other country, and need to be checked carefully.**
  - **According to German guidelines, the fatigue law is derived through Indirect Tensile Test at 20°C; its temperature dependency is ignored. It is exemplarily demonstrated for an aged/reclaimed asphalt mixture, that the results are misleading.**
- **A new approach for fatigue evaluation based on amplitude/ frequency sweep tests guarantees consideration of range of temperatures, and leads to reliable fatigue evaluation, while laboratory effort is not drastically increased.**

**Thank you!**

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- **Bitumen aging**
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